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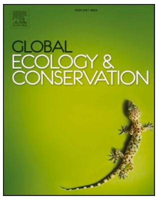

Global trends in sea turtle research and conservation: Using symposium abstracts to assess past biases and future opportunities

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ABSTRACT

We quantified research trends in the field of sea turtle science by collating data from 30 years of abstracts presented annually at the International Sea Turtle Symposium – the largest scientific symposia focusing exclusively on sea turtles. From the analysis of 7370 abstracts, we revealed five key findings: (1) loggerhead and green turtles were studied more than any other species; (2) the most studied Regional Management Units (RMUs) were typically those in the North Atlantic Ocean while the least studies were in the Indian Ocean; (3) almost half of all sea turtle studies were conducted on nesting beaches, leaving juveniles and adult males extensively understudied; (4) the most studied threat to sea turtles was fisheries bycatch although the proportion of studies on climate change increased rapidly after 2006; and (5) mark-recapture was the most utilized method for studying sea turtles but its use has dropped proportionately alongside an increased use of more modern tools such as satellite telemetry, stable isotope analysis, and genetics. We conclude that long-standing biases exist in sea turtle science and this has lead to many regions, habitats, and life-stages being chronically understudied. While trends suggest that these biases are slowly being addressed, efforts are still required to ensure that future studies effectively address the greatest conservation needs or fill the largest knowledge gaps on a truly global-scale.

1. Introduction

Within less than a century, the field of sea turtle research and conservation has matured to such an extent that it now sustains a growing and dynamic network of international collaborators (Mazaris et al., 2018) capable of conducting initiatives on a circumglobal scale (e.g., Kot et al., 2022; Wallace et al., In Press). These efforts have continually uncovered new insights into sea turtle ecology, such

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as revealing the long-distance migratory routes that connect many feeding and breeding habitats (Godley et al., 2008; Hays and Hawkes, 2018) or the capacity of sea turtles for deep and extended diving (Hochscheid, 2014). Simultaneously, widespread conservation efforts have made noteworthy progress in tackling the various threats faced by sea turtles (Rees et al., 2016; Mazaris et al., 2017). Considering the extensive output and achievements made by sea turtle researchers and conservationists worldwide, there is considerable value in assessing how these efforts have been distributed between species, regions, life-stages, or methodologies. By highlighting previous biases, future efforts can be guided towards understudied regions or topics with the greatest potential for research discovery and conservation impact.

The geographic ranges of each of the seven extant sea turtle species: loggerhead *Caretta caretta*, green *Chelonia mydas*, leatherback *Dermochelys coriacea*, hawksbill *Eretmochelys imbricata*, Kemp's ridley *Lepidochelys kempii*, olive ridley *Lepidochelys olivacea*, and flatback *Natator depressus* can be divided into reproductively isolated cohorts termed Regional Management Units (RMUs) (Wallace et al., 2010, In Press). As the name implies, these RMUs allow for population assessments and management decisions to be based on biologically relevant, rather than geopolitical, boundaries (Wallace et al., 2011). For example, reproductive cohorts of turtles spanning nesting beaches across several countries but within a single RMU may be managed or monitored as a single unit.

Despite the distinct, albeit overlapping, geographic ranges of the seven sea turtle species, all species largely follow a shared life-history pattern. Typically, hatchlings emerge from nests laid on tropical, subtropical, or temperate beaches before swimming to ocean gyres (Musick and Limpus, 2017). Juvenile turtles remain in these oceanic habitats until they eventually migrate to sub-adult foraging areas in either coastal or offshore habitats (Bolten et al., 2003). Upon reaching sexual maturity, both sexes migrate to breeding habitats near their natal beach (Lohmann et al., 2017). After males have copulated and females have laid all their eggs, they return to adult foraging habitats (Beal et al., 2022) and will repeat the same breeding migration every few years (Hays, 2000; Hays et al., 2022). As sea turtles utilize different habitats over their lifecycle, this affects how easily they can be encountered by humans. For example, nesting females can be encountered predictably by patrolling nesting beaches, while turtles may be more challenging to encounter and sample in-water. Due to this, several reviews based on expert-opinion have suggested that research and conservation efforts have been strongly biased towards nesting habitats, leaving non-nesting males and juveniles significantly understudied (Hays, 2008; Hamann et al., 2010). While evidence of such biases has been provided by quantitative meta-analyses focusing on satellite telemetry (Godley et al., 2008), this has not been the case in other meta-analyses such as those focusing on stable isotope analyses (Haywood et al., 2019) or sea turtle epibionts (Robinson and Pfaller, 2022).

As turtles utilize both coastal and offshore habitats, they are exposed to a diverse range of threats. Typical threats for turtles on nesting beaches, although not exclusive to these habitats, include habitat degradation (Fuentes et al., 2016); direct take of both eggs and/or adults (Senko et al., 2022a, 2022b); and predation by non-native species such as dogs, wild pigs, or raccoons (Cáceres-Farias et al., 2022). Climate change is having a major impact on sea turtle nesting populations due to the influence of elevated sand temperatures on hatching success and sex ratios (Santidrián Tomillo et al., 2015), sea level rise leading to loss of nesting habitats (Fuentes et al., 2010), and more frequent and extreme climatic events leading to an increasing risk of nesting inundation and erosion (Rivas et al., 2018). In contrast, turtles in offshore habitats are more typically threatened by fisheries bycatch (Wallace et al., 2013), entanglement in or ingestion of plastic debris (Roman et al., 2021), and contamination via chemical pollutants (Barraza et al., 2021). Elevated levels of chemical pollutants specifically have even been suggested to weaken turtles' resilience to diseases and thus could explain the growing prevalence of some diseases such as fibropapilloma (Keller et al., 2014). Finally, there are also the generally sublethal, and so difficult to quantify, impacts of unregulated and excessive ecotourism on sea turtles in both coastal and offshore habitats (Jacobson and Lopez, 1994; Zerr et al., 2022).

To study sea turtles and their threats, scientists and conservationists use an array of different techniques. For example, mark-recapture methods including physical tags or photo identification have frequently provided insights into population biology or movement patterns (e.g., Santidrián Tomillo et al., 2017; Buteler et al., 2022; Baldi et al., 2023). Satellite transmitters also provide information on long-distance movements but unlike mark-recapture methods, which only provide data upon capture events, telemetry devices allow for continual tracking of free-swimming animals (Godley et al., 2008; Hays and Hawkes, 2018). Genetics reveal reproductive interactions and evolutionary pathways scaling back millions of years (Jensen et al., 2013). Stomach content analyses provide specific data on animal diets (Bjorndal, 2017), while stable isotope analyses of superficial tissue samples provide general insights into the trophic level and geographic habitats where a turtle was previously feeding (Haywood et al., 2019). Molecular tools assess exposure to harmful chemicals by determining the concentration of heavy metals or Persistent Organic Pollutants (POPs) in sea turtle tissues (van de Merwe et al., 2010; Cortés-Gómez et al., 2017). Questionnaires or surveys collect information on human opinions or observations and can be particularly beneficial when generating information about systems that might be challenging to access (e.g., fisheries, Ortiz-Alvarez et al., 2020).

To better understand long-term trends and biases within the field of sea turtle research and conservation, we quantified data from abstracts presented at the annual International Sea Turtle Symposium (ISTS) between 1988 and 2018. Specifically, we codified data from all abstracts to reveal how efforts have varied across (1) species, (2) RMUs, (3) habitats, (4) life-stages, (5) sexes, (6) threats, and (7) methodologies. As the ISTS is the largest scientific symposium focusing exclusively on sea turtles, we assume that the abstracts can serve as a proxy for inferring global trends in sea turtle science. In addition, as the presentations given at the ISTS include studies that may never be published in peer-reviewed scientific publications, they arguably could provide a more holistic representation of the sea turtle community than achievable by reviewing exclusively peer-reviewed manuscripts. Finally, while there are already several data-driven assessment of trends and biases for specific sea turtle-focused topics (e.g., climate change – Patrício et al., 2021; epibiosis – Robinson and Pfaller, 2022) or methodologies (e.g., satellite telemetry – Godley et al., 1998, stable isotope analyses – Haywood et al., 2019), most assessments of sea turtle biology as a whole have utilized qualitative surveys of expert opinions (e.g. Hays, 2008; Hamann et al., 2010) or only used data from a couple of years (Rees et al., 2016). We therefore consider our data-driven and quantitative approach serves as a complimentary perspective to idenity previous biases in the field of sea turtle science and outline productive avenues for future research and conservation efforts.

2. Methods

2.1. Data source

We collected data from all abstracts presented at the ISTS between 1988 and 2018. The abstracts were published online after each symposium at https://www.internationalseaturtlesociety.org/publications/proceedings/ or https://repository.library.noaa.gov/. We began compiling information from the 8th ISTS in 1988 as earlier symposiums did not follow a formal abstract and presentation structure.

2.2. Database construction

Data were compiled simultaneously and in a complimentary manner to Robinson et al. (2022). For all oral or poster abstracts (excluding keynote presentations, video abstracts, or special sections on non-sea turtle species), we collected the following data:

(1) Study Species – We recorded the focal species in each abstract only if they were mentioned by name or could be deduced with certainty.
(2) Regional Management Unit (RMU) – We determined in which RMU(s) the study was conducted using the framework defined by Wallace et al. (2010) and updated in Wallace et al. (In Press). We defined the RMU(s) based on where the sampling took place and not where the analyses were conducted.
(3) Habitat – We categorized the habitat where turtles were encountered into the following categories. *Nesting beach* – for studies on nesting beaches. *In-water* – for studies in-water or for animals caught by fisheries. *Captivity* – for studies where turtles were in captivity. Eggs relocated to in situ beach hatcheries were not considered in captivity, but eggs incubated in laboratory settings were. *Dead/Stranding* – for studies on dead or stranded animals as long as they had not been caught by fisheries. Animals caught by fisheries were likely alive at the time of capture and in their natural habitats so were included in the *In-water* category. It should be noted that we recorded where the turtles were encountered and not necessarily where the data was relayed from. For example, if telemetry devices were deployed onto turtles on their nesting beaches but then tracked their in-water post-nesting migrations, this would still be listed as a nesting beach study.
(4) Life-Stage – We categorized the life-stages of the studied turtles into the following categories. *Hatchlings* – included turtles during the first week after hatching. *Juveniles* – included turtles older than one week after hatching but were not yet sexually mature. *Adults* – included sexually mature individuals. Finally, we also considered studies conducted on *Nesting Beaches* as a separate category due to difficulties in separating studies among adults, eggs, or hatchlings.
(5) Turtle Sex – We categorized the sex of the studied turtles into the following categories. *Female* – for studies on adult female turtles. *Male* – for studies on adult male turtles. *Both/Unknown* – for any study where either both sexes were studied or when the sex of the studied turtles was not reported. Finally, we also considered studies conducted on *Nesting Beaches* as a separate category. This was because even though most nesting beach studies are inherently conducted on nesting females, the eggs they produce may be of either sex.
(6) Threats – We recorded any mention of the following threats. *Climate Change* – defined as long-term changes in temperature, precipitation, other meteorological phenomena, or sea-level rise. *Fisheries Bycatch* – defined as incidental take and/or mortality of sea turtles by fisheries. This included the effects of ghost nets. *Habitat Degradation* – defined as any impact of anthropogenically-driven habitat changes such as building hotels on a nesting beach or the placement of an oil platform in a foraging area. This includes threats associated with habitat modification, such as light or sound pollution. *Direct Take* – included any instance where sea turtles or their eggs were harvested for human consumption or trade. *Pollution* – included physical (e.g., plastic), chemical, or radiation pollution. *Tourism / Ecotourism* – defined as any tourism or ecotourism-related activities that could lead to negative consequences for sea turtles such as disturbing nesting turtles or approaching sea turtles in-water. This category included boat strikes. *Pathogens / Parasites* – included pathogens or parasites on sea turtle populations. *Predators* – included non-human predators feeding directly on sea turtles of any life-stage.
(7) Methodology – We recorded whether the study provided data generated by one of the following methods. *Mark-Recapture* – included data used for individual identification and including recapture data from external, internal, or biological tags, genetic fingerprinting, or photographs. *Satellite Telemetry* – included data generated by satellite telemetry devices. *Genetics* – included data generated via genetic techniques (e.g., microsatellites, SNPs) but not genetic fingerprinting used in Mark-Recapture. *Stomach Contents* – included data on diet or plastic ingestion from stomach content analyses of necropsied turtles or lavage contents from live animals. *Stable Isotope Analyses* – included data generated via stable isotope analysis. *Heavy Metals / Persistent Organic Pollutants* – included data generated on heavy metals or Persistent Organic Pollutants found in sea turtle tissues. *Questionnaires / Surveys* – included data on human opinions or anecdotes generated from interviews.

2.3. Statistical analyses

Each abstract could have multiple entries for each of the previously listed categories. We calculated proportional representation by considering that each abstract had a maximum value of 1 for each category and if the study included multiple answers to a single category, this value was divided among the different answers. For example, a study conducted on both loggerhead and green turtles would be assigned a study species representation value of 0.5 for both loggerhead and green turtles.

We calculated changes over time in proportional representation within each catagory using linear least-squares regression in R (R Project V.4.1.2). We considered a statistically significant change when the linear regression revealed a directional increase or decrease $> 0.1\%$ per year. We used a linear least-squares regression as it provided a robust method to quantify change over time; however, we acknowledge that this method assumes all patterns follow a linear distribution.

3. Results

We analyzed 7370 abstracts from 29 annual ISTS events between 1988 and 2018, excluding those from 2012 and 2017 as the Book of Abstracts for these events were not publicly available at the time of writing this manuscript.

3.1. Species

The most studied species were loggerhead and green turtles, which featured in 30% and 29% of all abstracts respectively (Fig. 1). Both species also consistently featured in over 20% of abstracts each year. However, the proportion of studies on loggerhead turtles decreased by 0.1% per year, while the proportion for green turtles increased by 0.3% per year. Consequently, loggerhead turtles were the most studied species annually at the beginning of the study period but they were eventually superseded by green turtles. None of the remaining five species featured in more than 20% of abstracts in a single year with leatherback, hawksbill, olive ridley, Kemp's ridley, and flatback turtles constituting 14%, 11%, 9%, 4%, and 1% of all abstracts respectively (Fig. 1). The proportion of abstracts featuring olive ridley turtles increased by 0.2% per year, while those on Kemp's ridley turtles decreased by 0.4% per year. As such, more studies focused on Kemp's ridley than olive ridley turtles at the beginning of the study period but this pattern reversed over time. The proportion of abstracts featuring leatherback, hawksbill, and flatback turtles ranged from 7% to 20%, 5–17%, and 0–6% respectively and all remained relatively constant over the study period ($<0.1\%$ change per year).

3.2. RMUs

More studies were conducted on the Northwest Atlantic loggerhead turtle RMU (55%) (Fig. 2A) and North Atlantic green turtle RMU (36%) (Fig. 2B) than any other RMU for these species. For loggerhead turtles, the Mediterranean was the second most studied RMU with 21% of abstracts. All other loggerhead turtle RMUs in the Atlantic and Pacific each had between 3% and 8%, while those in the Indian Ocean had $< 1\%$. For green turtles, the East Pacific was the second most studied RMU with 19% of abstracts. All other green turtle RMUs had between 1% and 10%.

The most studied RMUs for leatherback and hawksbill turtles were, much like loggerhead and green turtles, in the Northwest Atlantic with 55% and 61% respectively. For leatherback turtles, the East Pacific and West Pacific were the second and third most researched RMUs with 24% and 10% respectively (Fig. 3 A0. The least studied leatherback RMUs were those in the Indian Ocean, which both had only 2% each. For hawksbill turtles, the East Pacific was also the second most studied RMU with 10%. All other

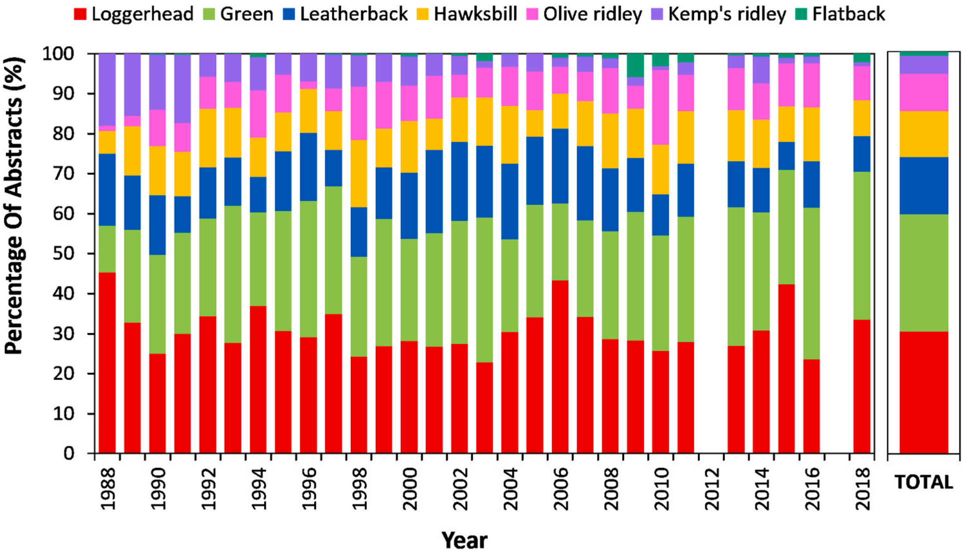

Fig. 1. Proportion of abstracts presented at the ISTS on each of the seven extent sea turtle species. The final bar on the right represents the cumulative sum over the entire study period.

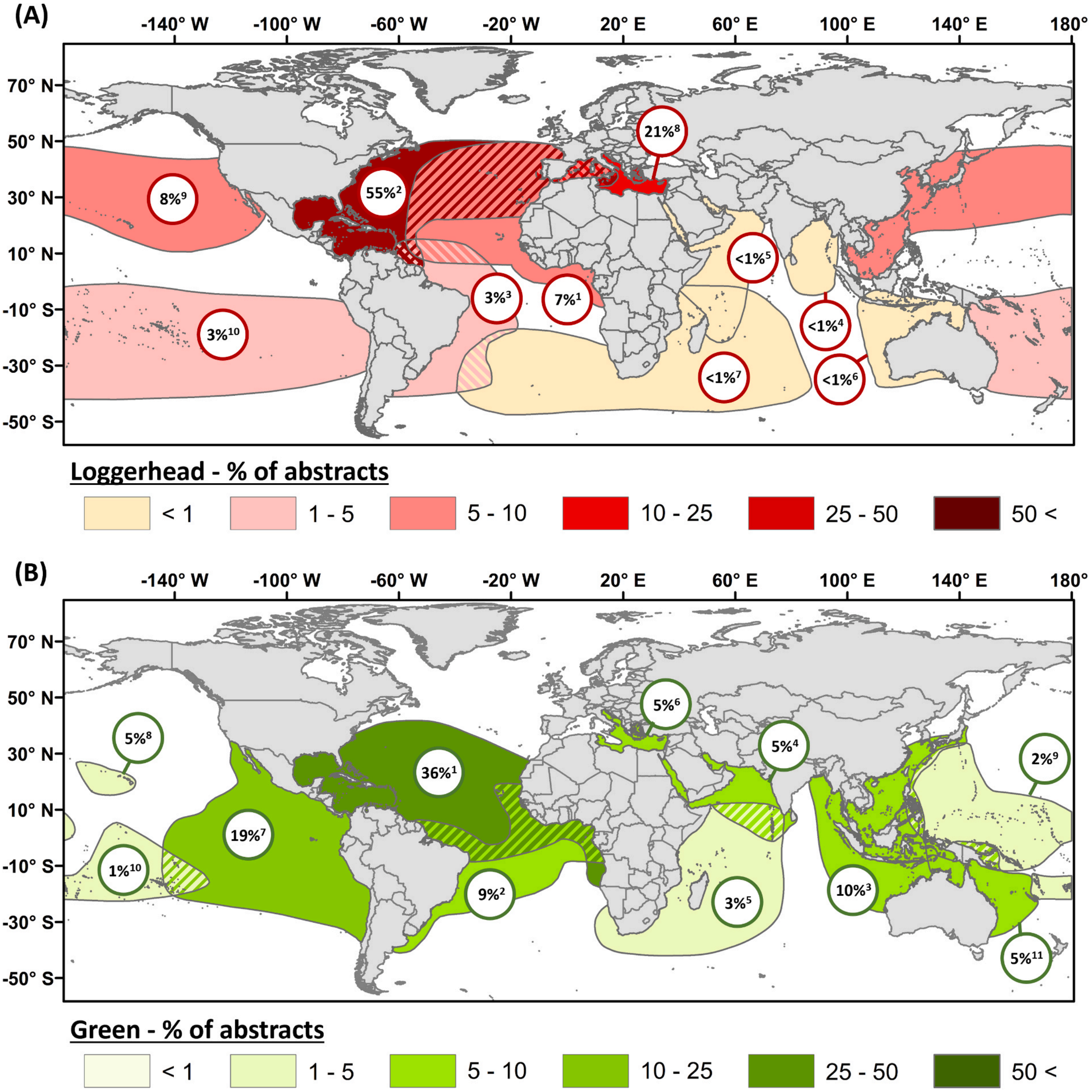

Fig. 2. Percentage of abstracts presented at the ISTS for each RMU of (A) loggerhead turtles (*Caretta caretta*) and (B) green turtles (*Chelonia mydas*). Colored polygons represent RMUs as defined in Wallace et al. (In Press) with darker polygons reflecting a higher proportion of abstracts. The circled numbers represent the percentage of abstracts from within each RMU. Subscript numbers refer to unique RMUs. Loggerheads turtles: ^{1}Atlantic – Northeast, ^{2}Atlantic – Northwest, ^{3}Atlantic – Southwest Atlantic, ^{4}Indian – Northeast, ^{5}Indian – Northwest, ^{6}Indian – Southeast, ^{7}Indian – Southwest, ^{8}Mediterranean, ^{9}Pacific – North, ^{10}Pacific – South. Green turtles: ^{1}Atlantic – North, ^{2}Atlantic – South, ^{3}Indian – East/Southeast Asia, ^{4}Indian – Northwest, ^{5}Indian – Southwest, ^{6}Mediteranean, ^{7}Pacific – East, ^{8}Pacific – North Central, ^{9}Pacific – West Central, ^{10}Pacific – South Central, ^{11}Pacific – Southwest.

hawksbill RMUs had less than 5% (Fig. 3B).

The Kemp's ridley turtle only had a single RMU so we combined it with the olive ridley turtle RMUs for these analyses (Fig. 4A). When considering ridley turtles collectively, the East Pacific was the most studied RMU with 44%. The Northwest Atlantic RMU for ridley turtles was only the second most studied with 29% even though it was the most studied RMU for all previously mentioned taxa. All other RMUs for ridley turtles had less than 8%. For flatback turtles (Fig. 4B), the Southeast Indian RMU had 59% while the Southwest Pacific RMU had only 39%.

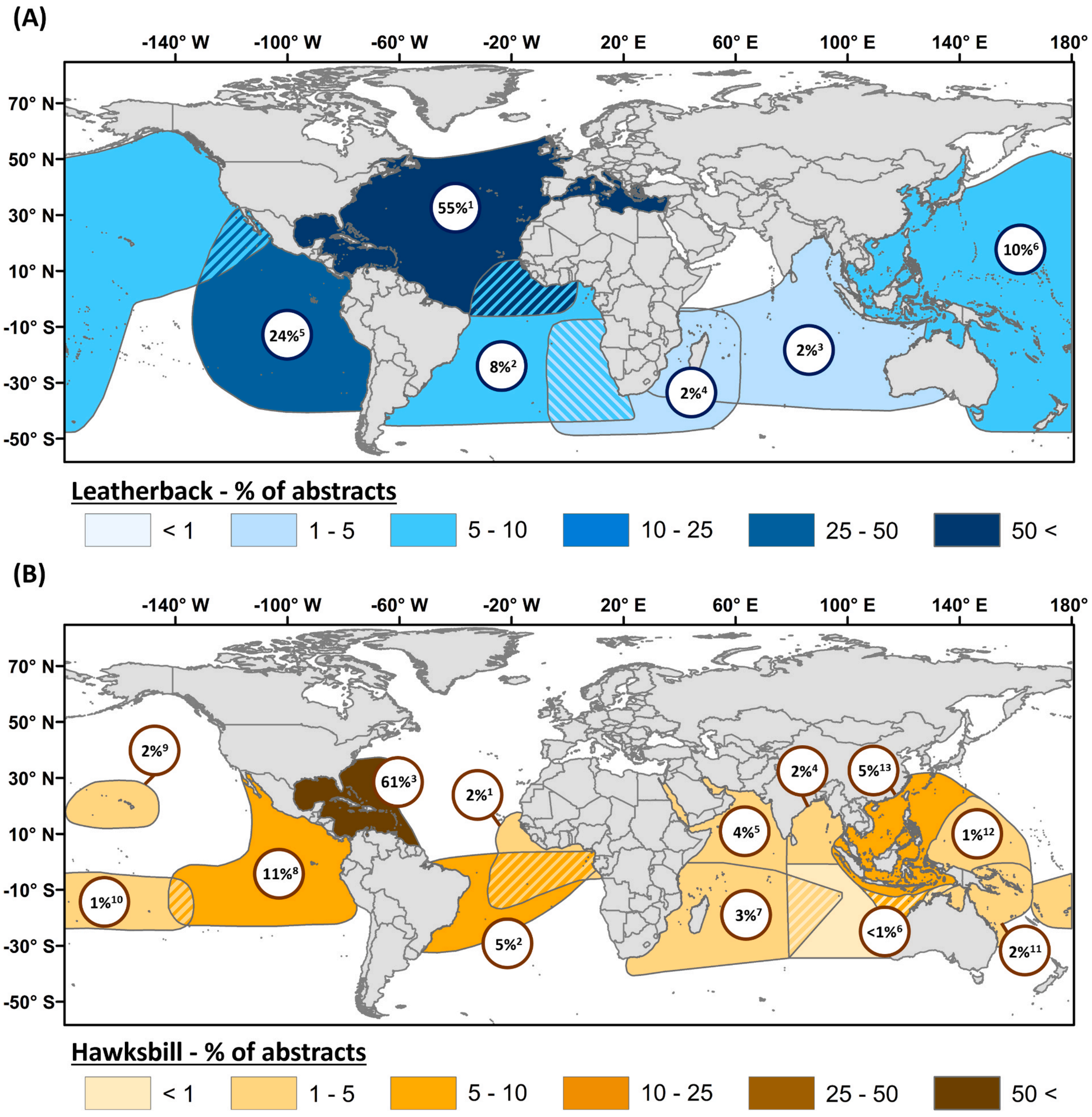

Fig. 3. Percentage of abstracts presented at the ISTS for each RMU of (A) leatherback turtles (*Dermochelys coriacea*) and (B) hawksbill turtles (*Eretmochelys imbricata*). Colored polygons represent RMUs as defined in Wallace et al. (In Press) with darker polygons reflecting a higher proportion of abstracts. The circled numbers represent the percentage of abstracts from within each RMU. Subscript numbers refer to unique RMUs. Leatherback turtles: ^{1}Atlantic – Northwest, ^{2}Atlantic – Southeast and Southwest, ^{3}Indian – Northwest, ^{4}Indian – Southwest, ^{5}Pacific – East, ^{6}Pacific – West. Hawksbill turtles: ^{1}Atlantic – East, ^{2}Atlantic – Southwest, ^{3}Atlantic – Northwest, ^{4}Indian – Northeast, ^{5}Indian – Northwest, ^{6}Indian – Southeast, ^{7}Indian – Southwest, ^{8}Pacific – East, ^{9}Pacific – North Central, ^{10}Pacific – South Central, ^{11}Pacific – Southwest, ^{12}Pacific – West Central, ^{13}Pacific – West/Southeast Asia.

3.3. Habitat, life-stage, and sex

Studies were predominantly conducted on nesting beaches (45.9%), which were focused on almost twice as much as in-water habitats (26.8%) (Fig. 5). However, the proportion of abstracts focusing on nesting beaches decreased by 0.3% per year, while it increased by 0.3% for in-water abstracts. The proportion of abstracts on dead turtles or those found stranded was only 7.7% and on turtles in captivity was only 4.8%, and both decreased in prevalence over the study period by 0.1% and 0.2% per year respectively. We were unable to categorize 14.8% of abstracts to a specific habitat.

More studies were conducted on juveniles (12.8%) than non-nesting adults (5.2%) or hatchlings (2.7%) (Fig. 6). As the proportion

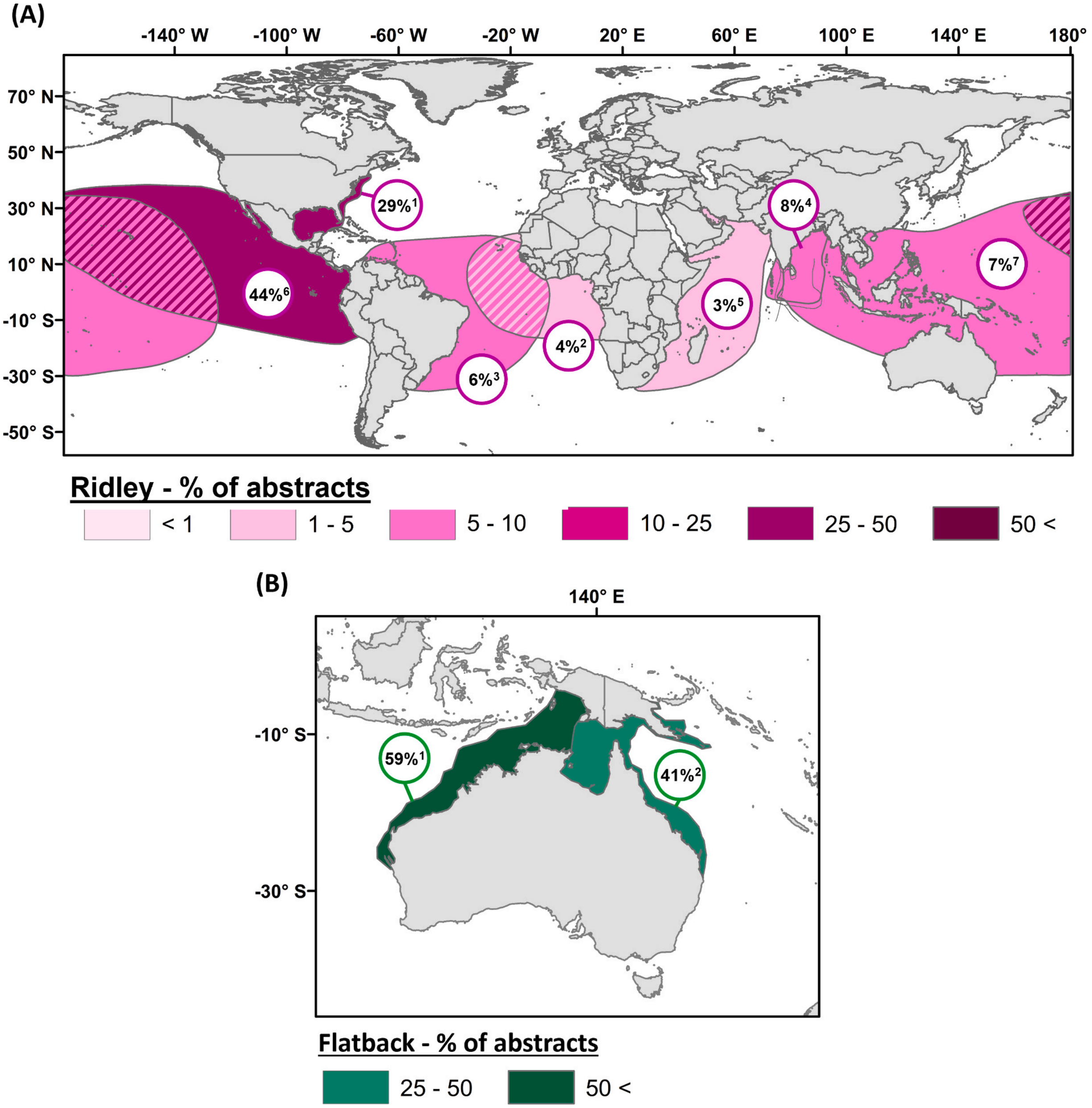

Fig. 4. Percentage of abstracts presented at the ISTS for each RMU of (A) ridley turtles (*Lepidochelys olivacea* and *L. kempii*) and (B) flatback turtles (*Natator depressus*). Colored polygons represent RMUs as defined in Wallace et al. (In Press) with darker polygons reflecting a higher proportion of abstracts. The circled numbers represent the percentage of abstracts from within each RMU. Subscript numbers refer to unique RMUs. Ridley turtles: ^{1}Atlantic – Northwest (this is the Kemp's ridley turtle, all other RMUs are olive ridley turtles), ^{2}Atlantic – East, ^{3}Indian – Northeast, ^{4}Indian – Northwest, ^{5}Indian – West, ^{6}Pacific – East, ^{7}Pacific – West. Flatback turtles: ^{1}Indian – Southeast, ^{2}Pacific – Southwest.

of studies on nesting beaches has declined (as mentioned in the previous section), this was mirrored by a 0.2% and 0.1% decline per year in the proportion of studies on adults and hatchlings respectively. Interestingly, the proportion of studies on juveniles remained relatively constant while it increased rapidly (0.6% per year) for studies on unknown life-stages.

The proportion of non-nesting beach abstracts that reported focusing exclusively on non-nesting male or female turtles was 0.5% and 1.0% respectively.

3.4. *Threats*

Over half (55.4%) of all abstracts mentioned at least one of the major threats faced by sea turtles, and this increased by 0.2% per

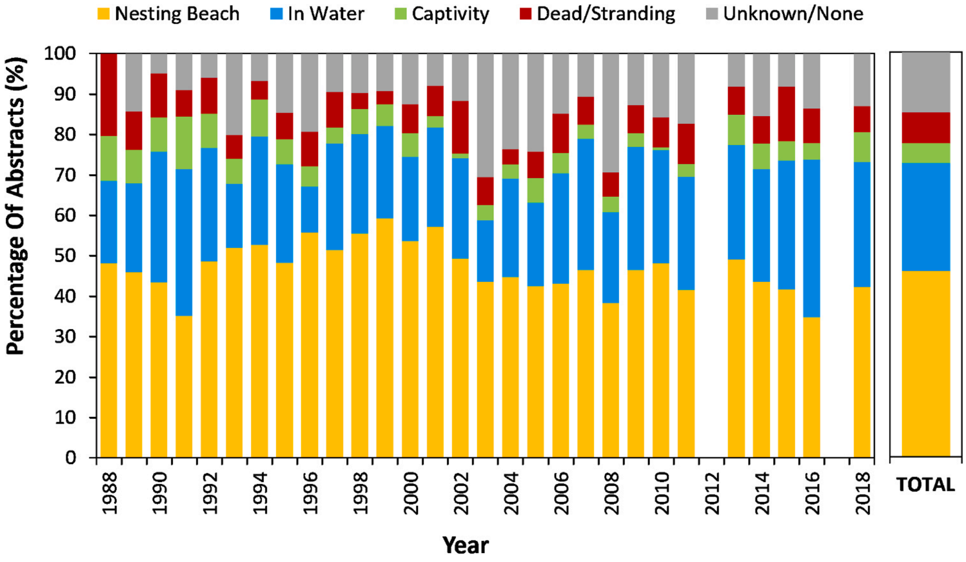

Fig. 5. Proportion of abstracts presented at the ISTS categorized by the habitat in which the turtles were encountered. The final bar on the right represents the cumulative sum over the entire study period.

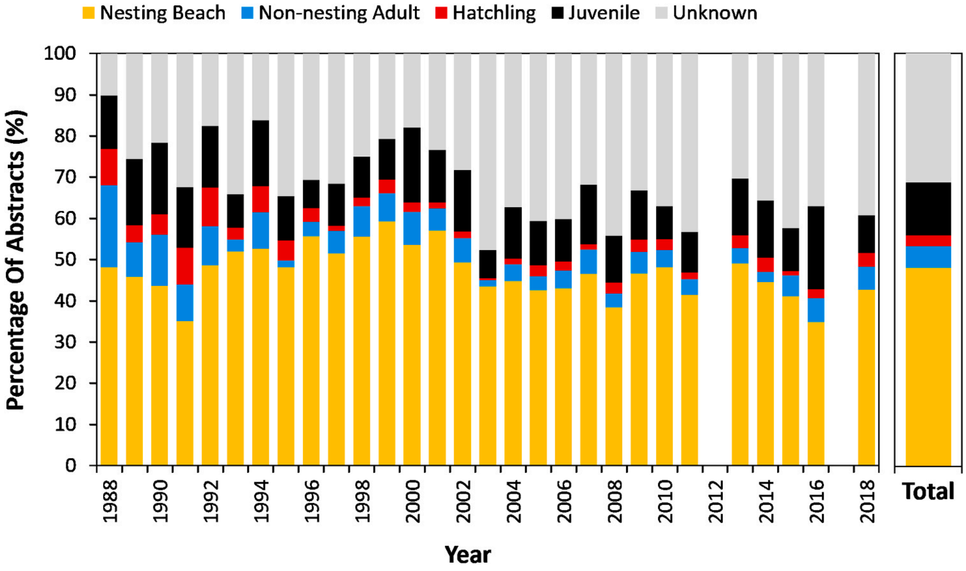

Fig. 6. Proportion of abstracts presented at the ISTS categorized by life-stage. The final bar on the right represents the cumulative sum over the entire study period.

year (Fig. 7). Fisheries bycatch was the most frequently mentioned threat at 16.2% and this increased by 0.3% per year. Direct-take was the second most-commonly mentioned threat at 10.7% and there was no change in the frequency at which this threat was mentioned over time. All other threats were mentioned in < 10% of abstracts and either showed a slowly decreasing or constant trend of representation. The one exception was climate change, which was first mentioned in 1992 and began to increase rapidly after 2006.

3.5. Research methodologies

Mark-recapture was the most common methodology being utilized in 10.0% of abstracts; however, its use decreased by 0.3% per year (Fig. 8). Studies using satellite telemetry devices and genetics were the second and third most common with 7.4% and 6.8% of abstracts respectively, and both increased by 0.2% per year. Questionnaires/surveys were used in 5.4% of studies and their use increased by 0.1%. All other methods were used in less than 3.0% of abstracts. Stable isotope analyses, while only being present in 1.5% of all abstracts, increased rapidly after 2010.

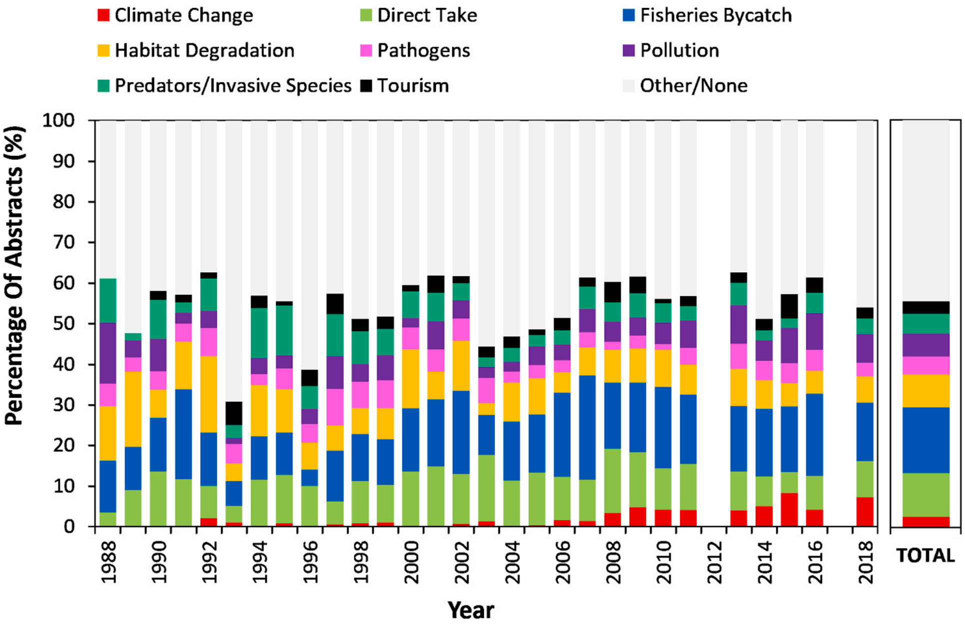

Fig. 7. Proportion of abstracts presented at the ISTS categorized by whether the study mentioned one of the key threats faced by sea turtles. The final bar on the right represents the cumulative sum over the entire study period.

4. Discussion

We provided a quantitative analysis to summarize global trends in sea turtle science over the past three decades. While many of these efforts are driven by local conservation needs, individual research interests, and availability of funding and human resources, this study provided a global perspective from which we can holistically evaluate whether the efforts of the sea turtle community are adapting to address previous identified knowledge gaps and biases.

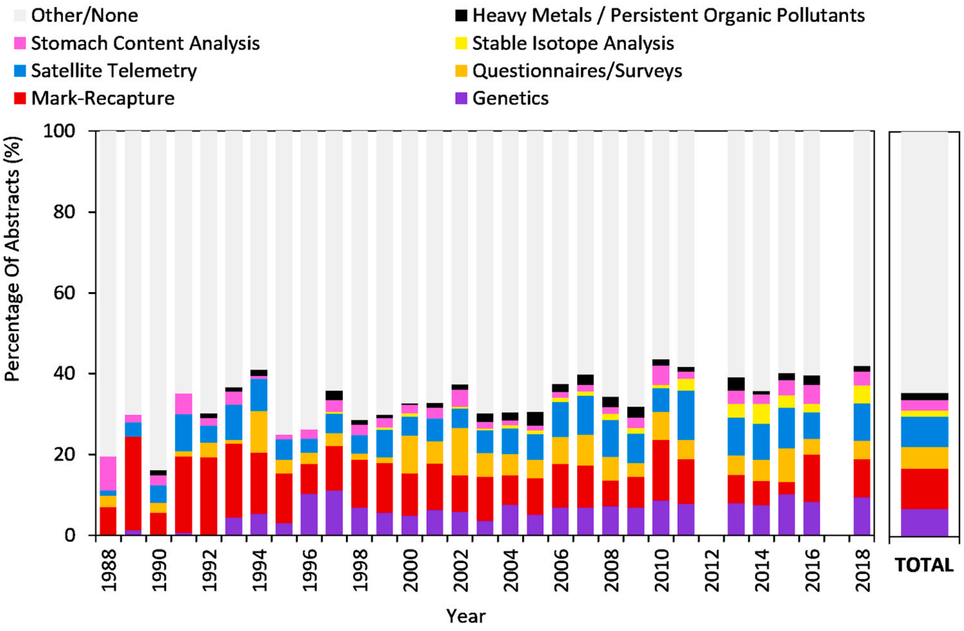

Fig. 8. Frequency of abstracts presented at the ISTS utilizing different research methodologies. The final bar on the right represents the cumulative sum over the entire study period.

4.1. Interspecific and geographic trends

It could be proposed that the most balanced, and arguably effective, method for studying sea turtles would be to divide research efforts equally between each of the seven extant species. From this perspective, our results reveal a clear bias towards loggerhead and green turtles with a contrasting bias against all other species except for leatherback turtles. Many other review articles and meta-analyses on sea turtles have observed similar patterns (e.g., Godley et al., 2008; Rees et al., 2016; Haywood et al., 2019); however, if we consider that research efforts should be divided equally between RMUs instead of species, we gain a more nuanced view of how past research efforts have been allocated. For example, the four most studied RMUs (in descending order: loggerhead – Northwest Atlantic, green – North Atlantic, leatherback – Northwest Atlantic, and hawksbill – West Caribbean) were from four different species yet were all in the Northwest Atlantic. Each of these species also had RMUs, typically in the Indian and West Pacific Oceans, that were in the lowest quarter of all studied RMUs. It is also interesting to note that when comparing the differences between species and between RMUs, the Kemp's ridley switches from being the second least studied species to one of the most studied RMUs (18 out of 49).

By taking an RMU perspective, it becomes clear that the perceived differences in research and conservation efforts between species are are largely driven by geographic trends. Instead of focusing future research efforts on understudied sea turtle species, a more effective method to promote scientific advancement could therefore be to promote further research efforts on specific regions. For example, research efforts could be focused towards, in descending order, the Indian Ocean, West Pacific, South Atlantic, East Pacific, and finally North Atlantic. Until these long-standing research biases are addressed, our understanding of these circumglobally distributed taxa will remain geographically and critically distorted. Focusing extra research efforts in the Indian and Pacific Oceans will also have key benefits for conservation as these regions host 10 of the 11 most endangered RMUs (Wallace et al., 2011). Indeed, a previous study focusing exclusively on stable isotope analyses on sea turtles also highlighted the disconnect between current research efforts and an RMUs conservation status (Pearson et al., 2017).

The geographic bias for sea turtle science to be conducted primarily in the North Atlantic, secondarily in the East Pacific, and then less elsewhere matches the broader "global north" vs "global south" divide that has been reported in other ecological reviews (Nuñez et al., 2021). A key factor driving such patterns is likely the observed correlation between a country's GDP and its scientific output (Asase et al., 2022) alongside global disparities in research funding and resources (Halpern et al., 2006; Huang and Huang, 2018). These differences in funding and resources in the sea turtle community could also explain why research biases towards loggerhead turtles, the most abundant species nesting in the USA (Ehrhart et al., 2014), have been more pronounced in sea turtle reviews that focus exclusively on more modern or expensive tools, such as stable isotope analyses (Haywood et al., 2019) and satellite transmitters (Godley et al., 2008).

Another factor that may lead to an over-representation of studies from North Atlantic in this study is that more ISTS events have been held in the USA than any other country. Futhermore, when the ISTS is hosted in a particular country, this is typically matched by an increase in the proportion of abstracts submitted from that country (Robinson et al., 2022). Nevertheless, the ISTS has increasingly been hosted outside of North America in the past two decades and this has been matched by a decrease in the proportion on studies on loggerhead, green turtle, and Kemp's ridley turtles – all of which have globally significant populations in US water – and a constrast increase in the proportion of studies on leatherback, hawksbill, and Kemp's ridley turtles. This alone could help explain that at least within the context of the ISTS, the biases toward the "global north" are slowly being addressed.

4.2. Life-history and demographic trends

Our data indicates that the majority of sea turtle science has previously been conducted on sea turtle nesting beaches supporting the qualitative claims made by expert-opinion based reviews in Hays (2008) and Hamann et al. (2010). The biases towards nesting beach research also have a "knock-on" effect on how research is divided between different demographics of turtles. For example, if we assume that half of all nesting beach studies exclusively focus on nesting females (the other half focusing on eggs and hatchlings), the proportion of studies of adult females still exceed those on juveniles by at least a factor of two. If we include an additional assumption that all non-nesting beach studies that focused exclusively on adult turtles were divided equally between the sexes, we can also estimate that adult females have been studied almost an order of magnitude (9.7 times) more than adult males. Consequently, there is a notable disparity in our knowledge of the ecology of adult females turtles compared to juveniles (Wildermann et al., 2018) and especially adult males (Hays et al., 2022).

To increase our knowledge of juvenile and adult male turtles will inherently require a rapid growth in in-water studies. Our data reveal that this is already happening, yet progress is understandably slow. Encountering and capturing turtles in-water is often much more logistically challenging and expensive than it is on nesting beaches. In some instances, these issues may be partially circumvented by technological innovations that allow for data to be collected on sea turtles remotely and without the need for animal handling, such as the use of Unoccupied Aerial Vehicles (Robinson et al., 2020; Yaney-Keller et al., 2021), stereo-video cameras (Siegfried et al., 2021), and photo-identification techniques (Schofield et al., 2008). In the future, it may even be possible to use satellite-derived imagery to study sea turtles by following methods similar to those currently being employed for whales (Cubaynes et al., 2019) and if combined with machine-learning photo-identification algorithms, it could enable global, and potentially, instantaneous assessments of sea turtle distribution and population status.

4.3. Research trends on sea turtle threats

The high proportion (55.4%) of abstracts mentioning at least one threat suggests that conservation is a key driving force behind sea turtle science. Furthermore, as the portion of abstracts mentioning threats has steadily increased this could be interpreted in multiple, non-mutually exclusive ways. Firstly, it could be that conservation is increasingly used as contextual justification for research efforts. Secondly, it could be that the severity of threats is increasing, promoting more efforts to tackle these issues. Lastly, there could be an increase in awareness and efforts to address potential threats to sea turtles even if the severity of the threat remains constant or even decreases. We are unable to separate between the three hypotheses in our analyses.

Our results align with many other studies that propose that fisheries bycatch is the largest global threat currently faced by sea turtles (e.g., Lewison and Crowder, 2007; Wallace et al., 2013; López-Mendilaharsu et al., 2020). Direct take and habitat development, which were the second and third most researched threats, are also known to pose a well-established risk to sea turtle populations (Fuentes et al., 2020; Senko et al., 2022a, 2022b). However, it is less clear whether the risk posed by many of the other threats is comparable to the amount of studies focusing on that threat. For example, while it is known that plastic pollution can lead to mortality via ingestion or entanglement (Duncan et al., 2017), many interactions with plastic are also non-fatal (e.g., Robinson and Figgener, 2015). In turn, this leads to difficulties in quantifying the extent of the threat posed by plastic pollution to sea turtle populations worldwide (Senko et al., 2020) and similar issues exist with non-fatal threats like tourism (Zerr et al., 2022). While it would therefore appear that the sea turtle community is effectively focusing its research efforts on key threats with the highest risk of mortality, further research is still needed to quantify the risk posed by many of the less researched and less understood threats.

It is also interesting to note that while most threats were already being mentioned at the beginning of the study period, mentions of climate change emerged more recently. Climate change was first mentioned in abstracts in 1992 but mentions of this threat rapidly increased after 2006 (Fig. 7), and this mirrors a similar increase in the number of publications throughout the broader scientific literature (Minx et al., 2017). Considering that most climate models suggest that global temperatures will continue to rise for several decades even under the most optimistic emissions targets (IPCC, 2021) and that climate change alone may lead to regional extirpation of specific sea turtle populations within the next 100 years (Santidrián Tomillo et al., 2015; Turkozan et al., 2021), we predict that the proportion of studies mentioning this threat will continue to increase for years to come.

4.4. *Trends in research methodologies*

Our results show that no single methodology dominates within the field of sea turtle research (Fig. 8). Mark-recapture was the most commonly used methodology but its relative frequency of use has been slowly declining. In contrast, we observed a proportional increase in the use of more “modern” methodologies, specifically: satellite telemetry, stable isotope analysis, and genetics. One explanation for this could be that there has been a considerable and steady decrease in the financial cost associated with more modern techniques in recent decades (Blanchong et al., 2016; Hays and Hawkes, 2018), while decreases in the cost of mark-recapture efforts may not have been as notable. Moreover, technological innovations in the modern methodologies, such as the incorporation of temperature-depth recorders into satellite transmitters, could mean that these techniques are generating ever-broadening data sets. Finally, there are also some instances where questions that would previously be answered via mark-recapture methodology can now be more effectively addressed with modern technologies. For example, satellite telemetry can provide more detailed and arguably less biased information on animal movements than mark-recapture (Perez et al., 2022) and may even be more cost-effective for animal tracking when studying life-stages that typically have low encounter rates (e.g., hatchlings). That said, we still predict that mark-recapture will remain the most-used methodology in sea turtle science for many years to come. This is partly because mark-recapture plays an essential role it plays in population assessments (e.g., Santidrián Tomillo et al., 2007) and long-term tracking of individuals (e.g., Monk et al., 2011) but also because developments in photo-identification and artificial intelligence could one-day negate the need for animal-handling in this process while simultaneously automating identification procedures.

In a review based on soliciting expert-opinions, Hamann et al. (2010) identified that there was a large need to increase the number of studies into the sociology aspects of sea turtle science. Rees et al. (2016) aimed to assess if the sea turtle community had responded to this call but still found social sciences to be largely underrepresented in this field. While we observed that studies including questionnaires / surveys were only the fourth most utilized methodology, the proportion of abstracts using this tool slowly increased over the study period. This is promising but it appears that the largest increases occurred in the early 1990 s and have slowed down since. Therefore, we believe that the use of social studies remains underutilized in sea turtle science, potentially limiting both scientific and conservation progress.

It was logistically infeasible to categorize and record all the varying methodologies used in ISTS abstracts, and so we concede that some important methodologies have been overlooked. Two of these that we anecdotally observed increasing especially in recent years are the use of temperature loggers within sea turtle nests, which is especially relevant in light of the growing impact of climate change (see Staines et al., 2022), and Unoccupied Aerial Vehicles (see Rees et al., 2018). We also note that in addition to tracking the frequency at which different methodologies are used, it would also be insightful to investigate how different methodologies are being combined in single studies. Indeed, recent reviews on the use of satellite telemetry and animal-borne cameras have suggested that the next scientific breakthroughs in the use of these tools will likely come by innovatively combining these technologies with other complimentary tools such as genetics or blood chemistry (Hays, 2015; Hays and Hawkes, 2018).

4.5. *Conclusion*

Here, we revealed that even though the field of sea turtle science has previously utilized a wide range of methodologies and focused intensively on each of the major threats currently faced by sea turtles, several research biases exist that have led to many regions, habitats, and life-stages being chronically understudied. Notably, there is a strong bias towards research being conducted in North

Atlantic RMUs, and research efforts in other RMUs appear to decline alongside increased distance from the USA. In addition, almost half of all studies have been conducted on nesting beaches meaning that non-nesting demographics, especially adult males and juveniles of either sex, are significantly understudied. Addressing these issues will require active efforts are needed to promote research efforts within Indian, Pacific, and South Atlantic RMUs with special focus on in-water projects. While there is evidence that the field of sea turtle science is organically addressing these biases, the slow rate of change means that active efforts are still needed to promote research efforts within Indian, Pacific, and South Atlantic RMUs with special focus on in-water projects. We stress that addressing these biases is key to developing a truly global and holistic understanding of sea turtle biology.

CRediT authorship contribution statement

Nathan J. Robinson conceived and designed the analyses, extracted data from the abstracts, conducted the data analyses, and wrote the article. Sofia Arias, Sophie K. Mills, Andrea Monte, Laura St.Andrews, Adam Yaney-Keller, and Christopher Gatto extracted data from the abstracts. Jacopo Aguzzi and Pilar Santidrián Tomillo provided guidance and constructive feedback on structuring the manuscript. All authors provided input during writing the manuscript.

Open research statement

Data provided for peer review (shared either privately or publicly in a repository).

Declaration of Competing Interest

We declare no conflicts of interest.

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References

Asase, A., Mzumara-Gawa, T.I., Owino, J.O., Peterson, A.T., Saupe, E., 2022. Replacing "parachute science" with "global science" in ecology and conservation biology. Conserv. Sci. Pract. 4 (5), e517.

Baldi, G., Furii, G., Del Vecchio, M., Salvemini, P., Vallini, C., Angelini, V., Casale, P., 2023. Behavioural plasticity in the use of a neritic foraging area by loggerhead sea turtles: insights from 37 years of capture–mark–recapture in the Adriatic Sea (Mediterranean Sea). ICES J. Mar. Sci. 80 (1), 210–217. https://doi.org/10.1093/icesjms/fsac227.

Barraza, A.D., Finlayson, K.A., Leusch, F.D., van de Merwe, J.P., 2021. Systematic review of reptile reproductive toxicology to inform future research directions on endangered or threatened species, such as sea turtles. Environ. Pollut. 286, 117470.

Beal, M., Catry, P., Regalla, A., Barbosa, C., Pires, A.J., Mestre, J., Patrício, A.R., 2022. Satellite tracking reveals sex-specific migration distance in green turtles (Chelonia mydas). Biol. Lett. 18 (9), 20220325. https://doi.org/10.1098/rsbl.2022.0325.

Bjorndal, K.A., 2017. Foraging ecology and nutrition of sea turtles. The Biology of Sea Turtles. CRC Press,, pp. 199–231. https://doi.org/10.1201/9780203737088.

Blanchong, J.A., Robinson, S.J., Samuel, M.D., Foster, J.T., 2016. Application of genetics and genomics to wildlife epidemiology. J. Wildlife Manag. 80 (4), 593–608.

Bolten, A.B., Lutz, P.L., Musick, J.A., Wyneken, J., 2003. Variation in sea turtle life history patterns: neritic vs. oceanic developmental stages. Biol. Sea Turtles 2, 243–257. https://doi.org/10.1201/9781420040807.

Buteler, C., Bardier, C., Cabrera, M.R., Gonzalez, Y., Vélez-Rubio, G.M., 2022. To tag or not to tag: comparative performance of tagging and photo-identification in a long-term mark-recapture of Juvenile Green Turtles (Chelonia mydas). Amph. Reptil. 1 (aop), 1–14. https://doi.org/10.1163/15685381-bja10119.

Cáceres-Farias, L., Reséndiz, E., Espinoza, J., Fernández-Sanz, H., Alfaro-Núñez, A., 2022. Threats and vulnerabilities for the globally distributed Olive Ridley (Lepidochelys olivacea) sea turtle: A historical and current status evaluation. Animals 12 (14), 1837. https://doi.org/10.3390/ani12141837.

Cortés-Gómez, A.A., Romero, D., Girondot, M., 2017. The current situation of inorganic elements in marine turtles: a general review and meta-analysis. Environ. Pollut. 229, 567–585. https://doi.org/10.1016/j.envpol.2017.06.077.

Cubaynes, H.C., Fretwell, P.T., Bamford, C., Gerrish, L., Jackson, J.A., 2019. Whales from space: four mysticete species described using new VHR satellite imagery. Mar. Mammal Sci. 35 (2), 466–491.

Duncan, E.M., Botterell, Z.L., Broderick, A.C., Galloway, T.S., Lindeque, P.K., Nuno, A., Godley, B.J., 2017. A global review of marine turtle entanglement in anthropogenic debris: a baseline for further action. Endang. Species Res. 34, 431–448. https://doi.org/10.3354/esr00865.

Ehrhart, L., Redfoot, W., Bagley, D., Mansfield, K., 2014. Long-term trends in loggerhead (Caretta caretta) nesting and reproductive success at an important western Atlantic rookery. Chelonian Conserv. Biol. 13 (2), 173–181.

Fuentes, M.M., Gredzens, C., Bateman, B.L., Boettcher, R., Ceriani, S.A., Godfrey, M.H., Radeloff, V.C., 2016. Conservation hotspots for marine turtle nesting in the United States based on coastal development. Ecol. Appl. 26 (8), 2708–2719. https://doi.org/10.1002/eap.1386.

Fuentes, M.M., Allstadt, A.J., Ceriani, S.A., Godfrey, M.H., Gredzens, C., Helmers, D., Bateman, B.L., 2020. Potential adaptability of marine turtles to climate change may be hindered by coastal development in the USA. Reg. Environ. Change 20, 1–14.

Fuentes, M.M.P.B., Limpus, C.J., Hamann, M., Dawson, J., 2010. Potential impacts of projected sea-level rise on sea turtle rookeries. Aquat. Conserv. Mar. Freshwater Ecosyst. 20 (2), 132–139.

Godley, B.J., Blumenthal, J.M., Broderick, A.C., Coyne, M.S., Godfrey, M.H., Hawkes, L.A., Witt, M.J., 2008. Satellite tracking of sea turtles: where have we been and where do we go next? Endang. Species Res. 4 (1–2), 3–22. https://doi.org/10.3354/esr00060.

Halpern, B.S., Pyke, C.R., Fox, H.E., Chris Haney, J., Schlaepfer, M.A., Zaradic, P., 2006. Gaps and mismatches between global conservation priorities and spending. Conserv. Biol. 20 (1), 56–64.

Hamann, M., Godfrey, M.H., Seminoff, J.A., Arthur, K., Barata, P.C.R., Bjorndal, K.A., Godley, B.J., 2010. Global research priorities for sea turtles: informing management and conservation in the 21st century. Endang. Species Res. 11 (3), 245–269.

Hays, G.C., 2000. The implications of variable remigration intervals for the assessment of population size in marine turtles. J. Theor. Biol. 206 (2), 221–227. https://doi.org/10.1006/jtbi.2000.2116.

Hays, G.C., 2008. Sea turtles: a review of some key recent discoveries and remaining questions. J. Exper. Marine Biol. Ecol. 356 (1–2), 1–7.

Hays, G.C., 2015. New insights: animal-borne cameras and accelerometers reveal the secret lives of cryptic species. J. Anim. Ecol. 84 (3), 587–589.

Hays, G.C., Shimada, T., Schofield, G., 2022. A review of how the biology of male sea turtles may help mitigate female-biased hatchling sex ratio skews in a warming climate. Marine Biol. 169 (7), 89. https://doi.org/10.1007/s00227-022-04074-3.

Hays, Graeme C., Hawkes, Lucy A., 2018. Satellite tracking sea turtles: Opportunities and challenges to address key questions. Front. Marine Sci. 5, 432.

Haywood, J.C., Fuller, W.J., Godley, B.J., Shutler, J.D., Widdicombe, S., Broderick, A.C., 2019. Global review and inventory: how stable isotopes are helping us understand ecology and inform conservation of marine turtles. Marine Ecol. Progress Ser. 613, 217–245. https://doi.org/10.3354/meps12889.

Hochscheid, Sandra, 2014. Why we mind sea turtles' underwater business: A review on the study of diving behavior. J. Exper. Marine Biol. Ecol. 450, 118–136.

Huang, M.H., Huang, M.J., 2018. An analysis of global research funding from subject field and funding agencies perspectives in the G9 countries. Scientometrics 115 (2), 833–847.

IPCC, 2021. Climate change 2021: the physical science basis. In: Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J.B.R., Maycock, T.K., Waterfield, T., Yelekçi, O., Yu, R., Zhou, B. (Eds.), Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 2391. https://doi.org/10.1017/9781009157896.

Jacobson, S.K., Lopez, A.F., 1994. Biological impacts of ecotourism: tourists and nesting turtles in Tortuguero National Park, Costa Rica. Wildlife Soc. Bull. 414–419.

Jensen, M.P., FitzSimmons, N.N., Dutton, P.H., Michael, P., 2013. Molecular genetics of sea turtles. Biol. Sea Turtles 3, 135–161.

Keller, J.M., Balazs, G.H., Nilsen, F., Rice, M., Work, T.M., Jensen, B.A., 2014. Investigating the potential role of persistent organic pollutants in Hawaiian green sea turtle fibropapillomatosis. Environ. Sci. Technol. 48 (14), 7807–7816.

Kot, C.Y., Åkesson, S., Alfaro-Shigueto, J., Amorocho Llanos, D.F., Antonopoulou, M., Balazs, G.H., Halpin, P.N., 2022. Network analysis of sea turtle movements and connectivity: A tool for conservation prioritization. Divers. Distrib. 28 (4), 810–829.

Lewison, R.L., Crowder, L.B., 2007. Putting longline bycatch of sea turtles into perspective. Conserv. Biol. 21 (1), 79–86. https://doi.org/10.1111/j.1523-1739.2006.00592.x.

Lohmann, K.J., Witherington, B.E., Lohmann, C.M., Salmon, M., 2017. Orientation, navigation, and natal beach homing in sea turtles. The Biology of Sea Turtles. CRC Press,, pp. 108–135. https://doi.org/10.1201/9780203737088.

López-Mendilaharsu, M., Giffoni, B., Monteiro, D., Prosdocimi, L., Vélez-Rubio, G.M., Fallabrino, A., Marcovaldi, M.Â., 2020. Multiple-threats analysis for loggerhead sea turtles in the southwest Atlantic Ocean. Endang. Species Res. 41, 183–196.

Mazaris, A.D., Gkazinou, C., Almpanidou, V., Balazs, G., 2018. The sociology of sea turtle research: evidence on a global expansion of co-authorship networks. Biodivers. Conserv. 27, 1503–1516. https://doi.org/10.1007/s10531-018-1506-1.

Mazaris, A.D., Schofield, G., Gkazinou, C., Almpanidou, V., Hays, G.C., 2017. Global sea turtle conservation successes. Sci. Adv. 3 (9), e1600730 https://doi.org/10.1126/sciadv.1600730.

Minx, J.C., Callaghan, M., Lamb, W.F., Garard, J., Edenhofer, O., 2017. Learning about climate change solutions in the IPCC and beyond. Environ. Sci. Pol. 77, 252–259. https://doi.org/10.1016/j.envsci.2017.05.014.

Monk, M.H., Berkson, J., Rivalan, P., 2011. Estimating demographic parameters for loggerhead sea turtles using mark–recapture data and a multistate model. Pop. Ecol. 53, 165–174.

Musick, J.A., Limpus, C.J., 2017. Habitat utilization and migration in juvenile sea turtles. The Biology of Sea Turtles. CRC Press,, pp. 137–163. https://doi.org/10.1201/9780203737088.

Nuñez, M.A., Chiuffo, M.C., Pauchard, A., Zenni, R.D., 2021. Making ecology really global. Trends Ecol. Evol. 36 (9), 766–769.

Ortiz-Alvarez, C., Pajuelo, M., Grados, D., Abrego, M.E., Rebeca Barragan-Rocha, A., Barrantes, M., Alfaro-Shigueto, J., 2020. Rapid assessments of leatherback small-scale fishery bycatch in internesting areas in the eastern Pacific Ocean. Front. Mar. Sci. 6, 813.

Patrício, A.R., Hawkes, L.A., Monsinjon, J.R., Godley, B.J., Fuentes, M.M., 2021. Climate change and marine turtles: Recent advances and future directions. Endang. Species Res. 44, 363–395.

Pearson, R.M., van de Merwe, J.P., Limpus, C.J., Connolly, R.M., 2017. Realignment of sea turtle isotope studies needed to match conservation priorities. Mar. Ecol. Prog. Ser. 583, 259–271.

Perez, M.A., Limpus, C.J., Hofmeister, K., Shimada, T., Strydom, A., Webster, E., Hamann, M., 2022. Satellite tagging and flipper tag recoveries reveal migration patterns and foraging distribution of loggerhead sea turtles (Caretta caretta) from eastern Australia. Mar. Biol. 169 (6), 80.

Rees, A.F., Alfaro-Shigueto, J., Barata, P.C.R., Bjorndal, K.A., Bolten, A.B., Bourjea, J., Godley, B.J., 2016. Are we working towards global research priorities for management and conservation of sea turtles? Endang. Species Res. 31, 337–382.

Rees, A.F., Avens, L., Ballorain, K., Bevan, E., Broderick, A.C., Carthy, R.R., Godley, B.J., 2018. The potential of unmanned aerial systems for sea turtle research and conservation: a review and future directions. Endang. Species Res. 35, 81–100.

Rivas, M.L., Spínola, M., Arrieta, H., Faife-Cabrera, M., 2018. Effect of extreme climatic events resulting in prolonged precipitation on the reproductive output of sea turtles. Anim. Conserv. 21 (5), 387–395.

Robinson, N.J., Figgener, C., 2015. Plastic straw found inside the nostril of an olive ridley sea turtle. Mar. Turt. Newsl. 147, 3.

Robinson, N.J., Pfaller, J.B., 2022. Sea turtle epibiosis: Global patterns and knowledge gaps. Front. Ecol. Evol. 10, 844021.

Robinson, N.J., Bigelow, W.F., Cuffley, J., Gary, M., Hoefer, S., Mills, S., Miguel Blanco, A., 2020. Validating the use of drones for monitoring the abundance and behaviour of juvenile green sea turtles in mangrove creeks in The Bahamas. Testudo 9 (2), 24–35.

Robinson, N.J., Mills, S., St.Andrews, L., Sundstrom, A., Thibodeau, J., Yaney-Keller, A., Gatto, C.R., 2022. Representation in sea turtle science: Slow progress towards gender equity and globalization revealed from thirty years of symposium abstracts. Front. Mar. Sci. 9, 943056 https://doi.org/10.3389/fmars.2022.943056.

Roman, L., Schuyler, Q., Wilcox, C., Hardesty, B.D., 2021. Plastic pollution is killing marine megafauna, but how do we prioritize policies to reduce mortality? Conserv. Lett. 14 (2), e12781 https://doi.org/10.1111/conl.12781.

Santidrián Tomillo, P., Genovart, M., Paladino, F.V., Spotila, J.R., Oro, D., 2015. Climate change overruns resilience conferred by temperature-dependent sex determination in sea turtles and threatens their survival. Glob. Change Biol. 21 (8), 2980–2988.

Santidrián Tomillo, P., Vélez, E., Reina, R.D., Piedra, R., Paladino, F.V., Spotila, J.R., 2007. Reassessment of the leatherback turtle (Dermochelys coriacea) nesting population at Parque Nacional Marino Las Baulas, Costa Rica: effects of conservation efforts. Chelonian Conserv. Biol. 6 (1), 54–62.

Santidrián Tomillo, P., Robinson, N.J., Sanz-Aguilar, A., Spotila, J.R., Paladino, F.V., Tavecchia, G., 2017. High and variable mortality of leatherback turtles reveal possible anthropogenic impacts. Ecology 98 (8), 2170–2179. https://doi.org/10.1002/ecy.1909.

Schofield, G., Katselidis, K.A., Dimopoulos, P., Pantis, J.D., 2008. Investigating the viability of photo-identification as an objective tool to study endangered sea turtle populations. J. Experim. Mar. Biol. Ecol. 360 (2), 103–108.

Senko, J.F., Nelms, S.E., Reavis, J.L., Witherington, B., Godley, B.J., Wallace, B.P., 2020. Understanding individual and population-level effects of plastic pollution on marine megafauna. Endang. Spec. Res. 43, 234–252. https://doi.org/10.3354/esr01064.

Senko, J.F., Burgher, K.M., del Mar Mancha-Cisneros, M., Godley, B.J., Kinan-Kelly, I., Fox, T., Wallace, B.P., 2022a. Global patterns of illegal marine turtle exploitation. Glob. Change Biol. 28 (22), 6509–6523.

Senko, J.F., Burgher, K.M., del Mar Mancha-Cisneros, M., Godley, B.J., Kinan-Kelly, I., Fox, T., Wallace, B.P., 2022b. Global patterns of illegal marine turtle exploitation. Glob. Change Biol. 28 (22), 6509–6523. https://doi.org/10.1111/gcb.16378.

Siegfried, T.R., Fuentes, M.M., Ware, M., Robinson, N.J., Roberto, E., Piacenza, J.R., Piacenza, S.E., 2021. Validating the use of stereo-video cameras to conduct remote measurements of sea turtles. Ecol. Evol. 11 (12), 8226–8237.

Staines, 2022. The ecological importance of the accuracy of environmental temperature measurements. Biol. Lett. 18, 20220263. https://doi.org/10.1098/rsbl.2022.0263.

Turkozan, O., Almpanidou, V., Yılmaz, C., Mazaris, A.D., 2021. Extreme thermal conditions in sea turtle nests jeopardize reproductive output. Clim. Change 167 (3–4), 30. https://doi.org/10.1007/s10584-021-03153-6.

van de Merwe, J.P., Hodge, M., Olszowy, H.A., Whittier, J.M., Lee, S.Y., 2010. Using blood samples to estimate persistent organic pollutants and metals in green sea turtles (Chelonia mydas). Mar. Pollut. Bull. 60 (4), 579–588.

Wallace, B.P., Kot, C.Y., DiMatteo, A.D., Lee, T., Crowder, L.B., Lewison, R.L., 2013. Impacts of fisheries bycatch on marine turtle populations worldwide: toward conservation and research priorities. Ecosphere 4 (3), 1–49.

Wallace, B.P., DiMatteo, A.D., Bolten, A.B., Chaloupka, M.Y., Hutchinson, B.J., Abreu-Grobois, F.A., Mast, R.B., 2011. Global conservation priorities for marine turtles. PloS One 6 (9), e24510. https://doi.org/10.1371/journal.pone.0024510.

Wallace, B.P., DiMatteo, A.D., Hurley, B.J., Finkbeiner, E.M., Bolten, A.B., Chaloupka, M.Y., Hutchinson, B.J., Abreu-Grobois, F.A., Amorocho, D., Bjorndal, K.A., Bourjea, J., Bowen, B.W., Briseño Dueñas, R., Casale, P., Choudhury, B.C., Costa, A., Dutton, P.H., Fallabrino, A., Girard, A., Girondot, M., Godfrey, M.H., Hamann, M., López-Mendilaharsu, M., Marcovaldi, M.A., Mortimer, J.A., Musick, J.A., Nel, R., Pilcher, N.J., Seminoff, J.A., Troëng, S., Witherington, B., Mast, R. B., 2010. Regional Management Units for marine turtles: a novel framework for prioritizing conservation and research across multiple scales. PLoS One 5, e15465. https://doi.org/10.1371/journal.pone.0015465.

Wallace B.P., Posnik Z.A., Hurley B.J., DiMatteo A.D., Bandimere A., Rodriguez I., Maxwell S.M., Meyer L., Brenner H., Jensen M.P., LaCasella E.L., Shamblin B.M., Abreu-Grobois F.A., Stewart K.R., Dutton P.H., Barrios-Garrido H., Dalleau M., Dell'Amico F., Eckert K.L., FitzSimmons N., García-Cruz M., Martins S., Mobaraki A., Mortimer J.A., Nel R., Phillott A.D., Pilcher N.J., Putman N., Rees A.F., Rguez-Baron J.M., Swaminathan A., Seminoff J.A., Turkozan O., Vargas S.M., Vernet P. D., Vilaça S.T., Whiting S.D., Hutchinson B.J., Casale P., Mast R.B. (In Press) Marine turtle regional management units 2.0: an updated framework for conservation and research of wide-ranging megafauna species. Endangered Species Research, in press. DOI:⟨https://doi.org/10.3354/esr01243⟩.

Wildermann, N.E., Gredzens, C., Avens, L., Barrios-Garrido, H.A., Bell, I., Blumenthal, J., Fuentes, M.M., 2018. Informing research priorities for immature sea turtles through expert elicitation. Endang. Species Res. 37, 55–76.

Yaney-Keller, A., San Martin, R., Reina, R.D., 2021. Comparison of UAV and boat surveys for detecting changes in breeding population dynamics of sea turtles. Remote Sens. 13 (15), 2857.

Zerr, K.M., Imlay, T.L., Horn, A.G., Slater, K.Y., 2022. Sick of attention: The effect of a stress-related disease on juvenile green sea turtle behaviour in the face of intense and prolonged tourism. Aquat. Conserv. Mar. Freshwater Ecosyst. 32 (3), 430–441. https://doi.org/10.1002/aqc.3773.